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U.S. DEPARTMENT OF THE NAVY
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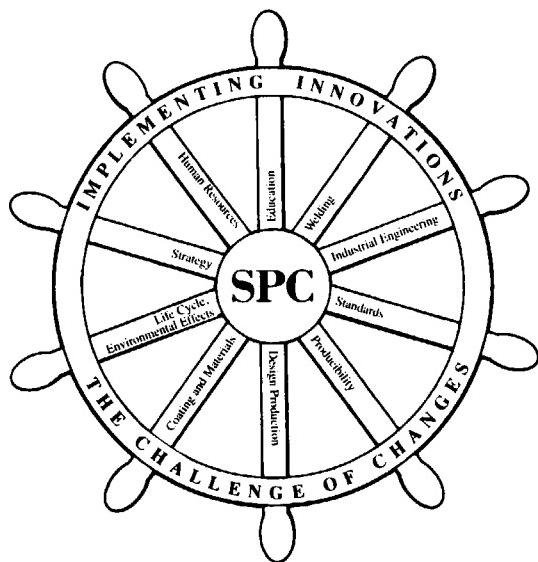
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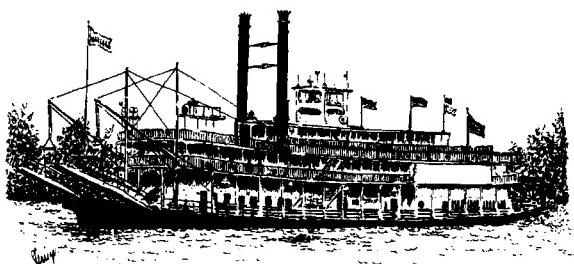
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Evaluation of the Hitachi Zosen Welding Robots for Shipbuilding

No. 8A-1

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ABSTRACT

The application of robotics provides good potential to increase welding productivity, reduce dependence on skilled labor and improve the competitive position of U.S. shipyards. However, shipyard applications have generally been limited to small part sizes and repetitive batch lots.

Hitachi Zosen of Japan has made considerable progress in developing and applying portable robotic welding equipment for welding primary ship's structure. These robots are not the conventional teach-playback variety, but rather a numerically-controlled (NC) robot that utilizes off-line programming making it particularly adaptable to high volume, non-repetitious welding tasks. The robot system was designed for ease of handling, minimal set-up time and operator intervention, and for use in smaller confined spaces. Unskilled operators rather than experienced welders can be used because of the robots off-line programming feature and computer control of the welding operation.

An initial technical evaluation, including a trip to Japan to observe the portable welding robots in operation, was completed under funding from the National Shipbuilding Research Program (NSRP). The evaluation concluded that the portable welding robot offers excellent potential in U.S. shipyards to reduce structural welding costs and improve overall productivity for commercial and naval ship construction.

INTRODUCTION

The NSRP SP-7 Welding Panel has continually monitored Japanese shipbuilding robotic welding applications. During a visit to

Japan in 1982, SP-7 members became aware of the planned development of the programmable portable welding robot. At that time, the design concept was under way but hardware development had not yet started.

In 1990, successful operation of the portable welding robot was observed at the Lindoe Shipyard in Denmark. The robots were impressive in their ease of set-up, operation, and programming. Productivity gains were evident since one operator was simultaneously running three robots with minimal intervention. As far as can be determined, this Danish shipyard is the only yard outside of Japan that is using these portable welding robots.

Because of potential value to the U.S. shipbuilding industry, a proposal for an evaluation of the portable welding robot was submitted to the SP-7 Welding Panel for consideration. The project concept was approved and a contract to complete an initial technical evaluation was subsequently awarded. The primary technical objectives of this evaluation were:

- observe the operational capabilities of the portable welding robot in a shipbuilding production environment;
- determine potential benefits in fabrication, productivity, quality and welding performance utilizing the portable welding robots; and
- evaluate the interface between the Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems and the ability of the robots to interface with shipyard computer design systems.

TRIP TO JAPAN

A team travelled to Japan in December, 1991 to visit shipyards that use the Hitachi Zosen portable welding robot. The authors, from Newport News Shipbuilding and Drydock Company, were joined on the trip by SP-7 Panel members from Peterson Builders, Inc., Ingalls Shipbuilding, Puget Sound Naval Shipyard, and the David Taylor Research Center.

The trip was beneficial in gaining an appreciation of Japanese advancements in robotics. For example, because of a shortage of workers, Japan has established a goal to replace one-third of its work force with robots. Through the use of robots and other automated processes, Japan has increased the yearly electrode consumption per welder per year from 907kg (1 ton) in 1980 to 5,262kg (5.8 tons) in 1990.

The following summarizes the highlights of the companies visited.

Hitachi Zosen Ariake Works

This yard, built in 1973, is Hitachi's largest and most modern with a capacity of six very large crude carriers (VLCC's) per year. Because of government-imposed constraints on capacity, the yard is only building four VLCC's per year. The yard employs approximately 1,200 people of which 400 are subcontractors.

Typical construction duration for a 240,000 - 300,000 DWT VLCC is about 9 months (3 months from start fabrication to keel, 3 months in the dry dock, and 3 months post launch).

The visit included a tour of their structural fabrication and assembly shops, final assembly areas, and dry docks. The portable welding robots were observed under actual production conditions. The team was provided technical presentations on the development, design, programming and operation of the robot as well as presentations on their robotic welding plans for the future.

Robotic welding currently accounts for 20% of their welding and their short-term goal is to achieve 50%. Their long-term goal is that 80% of all structural welding will be accomplished with robots and 95% of all welding will be accomplished in the flat or horizontal position.

Eighty-five percent of all structural welding and all robotic welding uses a specially formulated seamless flux-cored electrode.

Robots are predominately used for straight-line welding. Three-dimensional accuracy control is considered absolutely critical for robotic welding. Component parts are expected to be located within plus or minus 1mm (.039 inches) for welding.

Portable programmable robots and twin-torch, gantry-mounted robots are used for fillet welding stiffeners. When stiffener heights do not interfere, welds are made on both sides of a stiffener at the same time.

By the end of 1992, their panel line is expected to make extensive use of robotics and will be operated completely by unskilled labor.

Robots were observed welding fillets through a pre-construction primer (20+ 2 microns thickness). The primer is intended to last only one month. It was noted that slower welding speeds and a weaving technique were required for welding through the primer.

Hitachi Zosen Maizuru Works

This yard has 70 years of experience constructing commercial ships and surface vessels for the Japanese Navy. Maizuru also manufactures and sells automated systems for welding structural beam and column connection assemblies for the construction of buildings.

The yard runs both commercial and naval work through their shops at the same time. Ironically, they admitted that this was a real problem and were curious how U.S. shipyards were going to tackle the same problem.

The visit included a tour of the shops where the structural robotic welding systems are assembled. The twin torch gantry system and the extended reach robot system used by the Ariake Works are assembled at Maizuru Works.

The team also toured the dry dock area where construction of a double-hull VLCC using the recently developed unidirectional hull design was observed.

Sumitomo Heavy Industries (SHI) Oppama Shipyard

This yard was built in 1971 and has a capacity of six VLCC's per year. The yard is currently building 95,000 DWT tankers and 140,000 DWT bulk carriers.

Typical construction duration for a VLCC is about 12 months (3 months from start fab to keel, 5 months in the dock, and 4 months post launch).

The visit included an extensive tour of their structural fabrication and assembly shops and their dry dock area. Robotic welding applications include:

- robotic equipment for setting and fitting stiffeners to plate;
- single and double torch gantry systems for welding stiffeners to plate;
- a track-mounted articulated robot for welding stiffeners on small assemblies;
- eight Hitachi Zosen portable robots for welding primary hull structure;
- ten track-mounted robots for welding longitudinal stiffeners to transverse bulkheads; and
- four fixed-position robots for welding small and medium sized pipe flanges.

Overall, SHI utilizes 25 robots at this plant with plans to install an additional 25 robots. SHI estimates that their total investment in robotics is about 4 million U.S. dollars.

Daihen Corporation

The team visited Daihen Corporation, formerly known as Osaka Transformer Company. This plant manufactures robots, laser welding and cutting systems and operates a welding school to train and certify welders for other Japanese companies.

The plant was impressive in that 200 robots per month are assembled and tested by 14 people. Their streamlined production operation makes extensive use of Statistical Process Control (SPC)

and Just-In-Time (JIT) techniques. Daihen Corporation received the Deming Award in 1987.

OVERVIEW OF HITACHI ZOSEN PORTABLE WELDING ROBOT

The Hitachi Zosen portable welding robot, is a flexible, automated robotic welding system developed specifically for welding the primary (egg-box) structure at the assembly stage of unit construction. Physical attributes of the robot, including size, work envelope, load capacity and number of axes were chosen based on current and future ship designs.

The robot was designed for ease of handling, minimal set-up time and operator intervention, and for use in smaller confined spaces where a robot would be beneficial. The robot can be combined with a robot origin (self travelling) transfer unit (Figure 1) that expands the operating range of the robot to include travelling the full length of a structural bay between two longitudinal and transverse stiffeners. Stationary fixtures can be utilized to allow a wider range of robotic welding applications.

The portable welding robot is not a conventional teach-playback robot but rather a NC robot that utilizes off-line programming making it particularly adaptable to high-volume, non-repetitious structural welding tasks. The required machine control code is created by manual entry of design information into menu-driven, personal computer (PC)-based software.

Computer output is downloaded via floppy disc to the robot's controller on the shop floor. After loading the NC data, the robot operator may optionally add, delete, and insert data on the robot's control panel.

Because of its simplicity, one operator can operate three or more robots simultaneously. Each robot achieves an average arc-time of 50-70% and can deposit more than 20 Kg (44 pounds) of filler metal per eight hour shift.

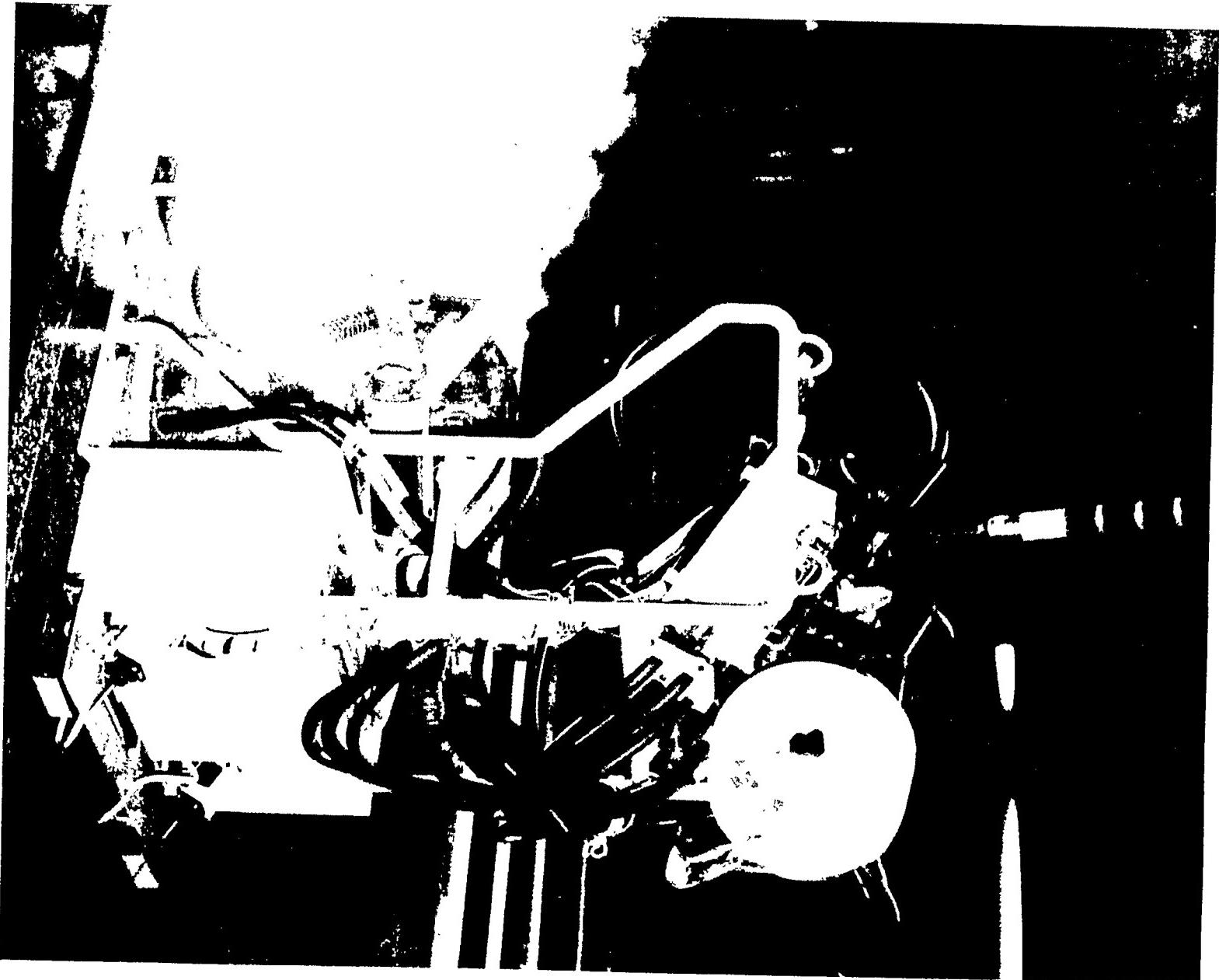


Figure 1. Portable Welding Robot

TECHNICAL EVALUATION

CAM System

The manufacturer has successfully developed a simple CAM system for operating the portable welding robot. Although a link between the portable robot CAM system and their CAD system has not been established, the robot was found to be easy to "program" through menu-driven software.

In addition to the robot and its controller, the system includes: a PC with minimum 1 MB **RAM**, 20 MB hard drive and 3.5" floppy disc drive; a monochrome or color monitor; a 15" printer; and the NC data generation software.

Robot NC Data Generation Software. The robot data generation software provides a menu-driven system for a planner to describe and input the geometry of a section of the ship's structure. Principal features include:

- fundamental hull structure geometry that depicts the basic structural configuration (skin plating with two longitudinal frames and two transverse bulkheads);
- a library of variables for the fundamental hull structure such as type and size of longitudinal stiffeners, frame spacing, types of brackets and collars, etc.;
- a library of welding parameters dependent on single or multi-pass weld and leg lengths and position;
- automatic simulation of trajectories (not displayed) to minimize starts and stops depending on the limitations of the robot movement;
- automatic generation of opposite side weld paths;
- an interference avoidance check between movement of the robot and ships structure; and
- automatic generation of machine language code.

Data Entry/Programming. The team was provided a demonstration of data input for

programming a typical portion of a ship's structure. The following summarizes the steps of that operation:

1. A planner uses either a CAD design on a computer terminal or a drawing that depicts the structural area to be programmed. For purposes of the demonstration, the following sketch (Figure 2) was used:

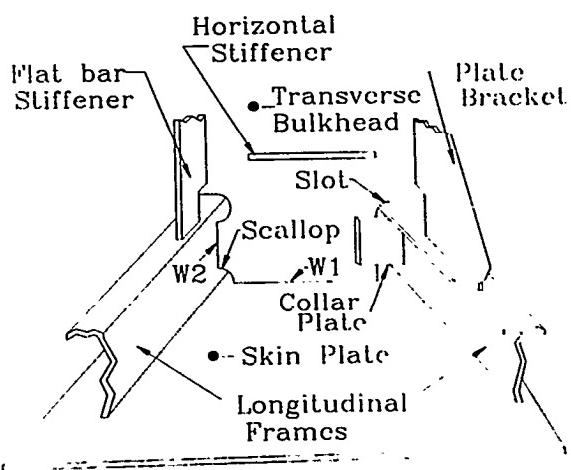


Figure 2. Basic hull structure used for demonstration

2. The planner then accesses the PC software and manually enters the geometric description of the space to be welded. There are 27 variables that define the geometry including types of stiffeners, fitting angles, and overall lengths of the space. Table I provides a sample of the data entered for the demonstration.

The variables also include the selection of any of 25 slot and 6 collar arrangements. A sample of typical slot and collar arrangements is provided in Figure 3.

Variable	Input data
Long'l floor angle	90°
Long'space	860 cm
Long'l web depth	300 mm
Floor thickness	12.5 mm
Slot type	A712
Weld type	Fillet
Leg length: W1	6.0 mm
W2	7.0 mm

Table I. Data entered demonstration

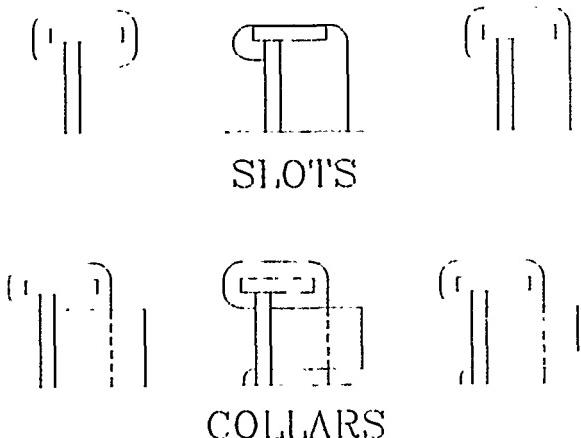


Figure 3. Slot and collar arrangements

- Upon completion of data entry, the software automatically optimizes weld trajectories by running simulation and interference checks, and then develops the machine language code for the robot's controller.

Structural Data Output. The generated NC data is transferred onto a floppy disc for loading into the robot's controller when the structural welding is to be completed.

An additional unique output is a summary of the projected elapsed times for completing the actual welding of the area.

Assessment of CAM System. Based on the demonstration provided, programming the robot appears to be relatively easy and straight-forward. A planner should quickly become proficient at entering the required design input. Because of the repetitive nature of the ship's structure within each block/unit, data entry costs should be minimal.

Direct input from a CAD database would be an enhancement and is technically feasible. However, the lack of this interface is not a significant drawback due to the minimal time required for manual data entry.

The robot's software is designed to work with metric dimensioning while U.S. designs are typically based on feet and inches. This is not a significant problem since most CAD systems can easily convert between the two.

The software can be modified to accommodate design details specific to another shipyards design.

Operating The Robot

To start production welding, the operator lowers the robot onto the structural assembly using a dedicated overhead bridge crane. Because of its relatively small physical size and weight, the operator can easily slide the robot into position. Placement of the robot within the structure is not critical; however, there is a target location near the weld start point for initial alignment.

A job identification number links the CAM generated data to the egg-box structure to be welded. The operator inputs the identification number into the control pendant which downloads all required machine control code to the robot.

When coupled with the robot origin (self-travelling) transfer unit, the robot uses ultrasonic sensors to determine its distance from the transverse frame, and infrared sensors to determine its distance from the longitudinal stiffeners. This feedback is compared to the CAM design data that defined the zone required to complete the welds. The robot then guides itself to the necessary location and begins the welding operation.

After the welds joining the skin plate to the first transverse bulkhead are completed, the robot

completes the horizontal fillet welds joining the skin plate to the longitudinal frames. Because of the closeness of the longitudinal frames on the production application the team observed, the robot was unable to turn itself around to complete the welds at the other end of the egg-box structure. In this case, the crane was used to re-orient the robot to complete the welding.

Equipment

Power supply cables, shielding gas lines, and control cables are conveniently supplied by an overhead bridge crane. This crane also is used to move the robot from location to location within the sub-assembly.

The 1.2mm (.047 inch) diameter electrode is supplied in spools weighing approximately 3.6 kg (30 lbs.) One hundred percent carbon dioxide shielding gas is utilized. The electrode drive mechanism is of the single roll type with a wire straightener. To increase accessibility of the torch, the contact tip is extended approximately 19mm (.75 inch) from the gas cup.

Detailed specifications for the robot and origin transfer unit and a summary of the overall capabilities of the portable robot can be obtained in the complete technical evaluation report completed for SP-7.

Weld Tracking

Once positioned inside the structure, touch sensing is used to determine the actual location of the beginning and ends of each weld. Depending **on the** weld's accessibility, each start or stop location is found using either two or three search patterns. Prior to each search, approximately 51mm (2.0 inches) of electrode is extended from the contact tip to serve as the touch sensing surface. The wire straightener is used to reduce electrode deflection as it exits the contact tip and to increase the accuracy of the search.

The touch sensing system utilizes a 400 volt charge applied to the welding electrode and was observed sensing through primer-coated steel.

Through-the-arc seam tracking is used to track the joint after welding has started. This tracking method is only applied on longer length

welds such as the horizontal fillet weld joining the longitudinal stiffeners to skin plate.

Mechanical contact sensors are utilized to prevent the robot from backing into the transverse bulkhead at the other end of the space.

Weld Sequence and Fillet Weld Sizes

The sequence of welding is established during the CAM movement simulation. This feature optimizes the order in which the welds are completed and reduces both the number of weld starts and stops and the overall distance the robot must travel.

Horizontal fillet welds are made using one pass with a weave. Vertical fillet welds are completed using two passes: a non-weaving, downhand weld is completed first to seal any gap that may exist in the fit-up; an uphand weld is then made using a weave to obtain the desired fillet weld size. When using the downhand technique, root gaps of up to 3mm (.118 inch) can effectively be sealed. Root gaps in excess of 3mm (.118 inch) result in unacceptable weld quality.

The welds observed were approximately 8mm (-315 inch) vertical and horizontal fillet welds. As illustrated in Tables II and III below, weld schedules containing the welding parameters and weaving conditions for vertical and horizontal fillet welds have been developed.

Fillet size	Position	
	Flat	Vert.
4 mm (.157")	X	
5 mm (.197")	X	X
6 mm (.236")	X	X
7 mm (.276")	X	X
8 mm (.315")	X	X
9 mm (.354")	X	X
10 mm (.394")		X

Table II Fillet weld sizes using a single pass technique

Fillet Size	Number of Passes
9 mm (.354")	2
10 mm (.394")	2
11 mm (.433")	2
12 mm (.472")	3
13 mm (.512")	3
14 mm (.551")	3

Table III Fillet weld sizes using a multi-pass technique

The task of creating this database was simplified by limiting the welding to the Flux Cored Arc Welding (FCAW) process and a single electrode diameter.

Multiple pass welds of up to three passes are possible, however; through-the-arc seam tracking is limited to the first pass. Additional passes are simply offset from the initial pass. The robot operator was observed making slight adjustments to correct the stickout length during a vertical weldment.

Flux Core Electrode Development

In 1981, Ariake Works reviewed the welding processes and consumables they used to determine how they could increase production through process optimization. At that time, 60% of the welding was completed with the shielded metal arc welding process with semi-automatic gas metal arc welding comprising only 20%. With the intent to substantially increase the application of automation and robotics, they pursued wide implementation of the FCAW process for several reasons.

- FCAW has the highest deposition rate for a given amperage.
- FCAW has the most consistent feedability of any consumable. This is an important requirement when using robotic seam tracking.
- With the introduction of a seamless FCAW consumable, extremely low diffusible hydrogen values are obtainable.

In a joint venture with Nippon Steel, Ariake Works developed a flux-cored electrode/carbon dioxide shielding gas combination specially formulated to weld through primer-coated surfaces. Work is continuing to improve the consumable to reduce smoke emissions.

Since Nippon Steel is the only producer of that special electrode, arrangements would have to be made either to purchase it from Nippon or request that a United States wire manufacturer develop an alternate electrode. The fillet weld size database may have to be adjusted if an alternate welding consumable or process is used.

Overall, weld quality was considered satisfactory. In some cases, however, the team observed welds that would have been questionable if inspected to U.S. regulatory standards.

Training

Due to the computer's virtual control of the welding process, skilled welders are not required for operating the robot. The strategy at Ariake Works is to train unskilled individuals to be robotic equipment operators and utilize skilled welders in other production areas.

Operator training consists of a one-week safety course, a one-week robot operations course, and one week of on-the-job training. At the end of the three weeks, the operator is fully capable of operating the robot in production.

Safety

As with any automated robotic system, safety to the human operator is a major concern. Many of the safety concerns have been reduced by limiting the power output of the robot and the origin transfer unit motors. The drive motors of the origin transfer unit have a power output of only 80 watts, thus posing minimal danger to the operator.

The robot operator has access to an emergency stop button located on the control pendant. Visual indication of the robot's operational status is provided by a system of four colored lights located on the transfer unit.

Safety issues pertaining to U.S. shipyards must be addressed to identify any requirements that would hinder the system's flexibility.

Maintenance

Ariake Works reported that the robots have been very durable and that only routine maintenance is required.

One robot has been in a production atmosphere since 1985 without any mechanical failure. One reason for this durability record may lie in the use of off-line programming coupled with the collision avoidance feature. The primary source of wear on a conventional teach-playback robotic system results from collisions between the robot and the work piece during programming.

Planned Applications

At the time of the visit to Ariake Works, a system comprised of one robot and a three-axis gantry was being developed for the next step of their subassembly stage. Initial implementation of the system will rely on simple CAM data generated on a PC. Depending on the progress of the application software, a gantry system utilizing four robots on one gantry will be integrated to allow the welding of more complex subassemblies. Tremendous flexibility will be gained when the robotic cell is linked to the CADCAM system allowing the welding of non-repetitious pieces. The CADCAM linkage will also allow one of the four robots to fail and have its work completed by the remaining three.

HITACHI ZOSEN ISSUES

Although the manufacturer is clearly interested in selling the robots to U.S. shipyards, two concerns were expressed.

1. The first concern is the issue of third party product liability in the event the robots were used in constructing a ship that failed for any reason.
2. The second concern is patent protection since there may already be patents or patent applications for similar equipment in the United States

PERSPECTIVE ON CONSTRUCTION PHILOSOPHY

While this report provides a technical evaluation of the portable welding robot, an appreciation of its development and how it fits into the overall construction philosophy of the shipyard is important.

There is a hidden danger in selectively "picking and choosing" individual elements of Japanese shipbuilding technology for use in U.S. shipyards. In the case of the portable welding robot, the danger lies in the all-too-typical approach of purchasing automated equipment (islands of automation) but not integrating that equipment with the design, process planning, and construction effort.

The portable welding robot should not be viewed as the end product of years of research and development, but rather as a significant pre-planned and achieved milestone in the design of long-range ship construction improvements. At Ariake Works, these improvements have focused on streamlining production processes and increasing the volume of work completed at the earliest stages of construction. The focus in welding has obviously been in developing assembly processes that complete as much welding indoors in the flat position as possible. Work is designed and grouped according to its shape and joint type to achieve the highest percentage of automatic welding. New ship designs incorporate and take advantage of the full range of robotic capabilities by considering weld size, length, position, space restrictions, etc.

Hitachi Zosen has a company-wide philosophy that strives to reduce costs while eliminating dirty, difficult and dangerous work. It was obvious that the portable welding robots were not developed as islands of automation, but rather as pre-conceived and integral elements of continuous process control and improvement.

Based on the authors' observations at Ariake Works and at SHI Oppama Works, there are several characteristics of a successful application of robotic welding technology.

- Ship designs are developed with a strong consideration of welding processes and joining techniques.

- Ship designs that incorporate well-defined manufacturing processes and process controls including Just-In-Time techniques, detailed planning, and SPC where appropriate.
- An integrated working relationship exists between design, planning and manufacturing to facilitate process flow and facility utilization.
- All work is planned and standardized to make maximum use of the work force and minimize downtime.
- Long range plans for construction process improvements are developed including the expanded use of CAD/CAM systems; standard designs that facilitate manufacturing automation such as robotic welding, cutting, plate marking, painting; and the advancement of three dimensional accuracy control.
- A strong emphasis on management involvement and commitment to continuous process improvement.
- Automation and related technology applications are simple and not “over-kill” for the particular application;
- Specific design details will have to be reviewed to determine if changes in the robot software are required.
- Metric dimensioning will have to be provided to input the required geometric data.
- The availability of the flux-cored weld wire from Nippon Steel will have to be determined. An alternate source or consumable may require modifications to the weld schedule database.
- Safety issues related to a mobile robot must be addressed.
- Procedure qualifications permitting downhand welding will need to be developed for naval products.
- Process controls will be required for fabrication and fit-up to meet the tolerances of the robot.
- Overall weld quality, particularly vertical welds, will have to be assessed in terms of U.S. regulatory requirements.
- The effectiveness of the touch sensing system on paint and mill scale will have to be determined.

SUMMARY

Based on observations of the portable welding robots in a production environment and the satisfactory results of the technical review, the portable welding robots offer excellent potential to reduce structural welding costs and increase overall productivity. The relative ease of programming provides a wide variety of potential applications for both commercial and naval shipbuilding in the United States.

The following summarizes the issues that a U. S. shipyard will have to resolve to ensure successful implementation of the portable welding robots.

- Progress in resolving the manufacturer's third person product liability and patent protection rights will have to be monitored.

The authors believe the above issues can be successfully resolved, and have recommended that the NSRP fund the purchase of at least one Hitachi Zosen portable welding robot with the robot origin transfer unit for further evaluation by a U.S. shipyard.

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Copies of the SP-7 final report "Evaluation of the Hitachi Zosen Portable Welding Robot" can be obtained by contacting:

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